INVESTIGATION OF FRACTURE IN THE T1 TANKER CAPITAN

BY

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SHIP STRUCTURE COMMITTEE

Convened by
The Secretary of the Treasury

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U. S. ARMY
U. S. NAVY
U. S. COAST GUARD
U. S. MARITIME COMMISSION
AMERICAN BUREAU OF SHIPPING

SEPTEMBER 27, 1949

SHIP STRUCTURE COMMITTEE
Washington 25, D. C.

September 27, 1949

Naval Attache
Argentine Embassy
Washington, D. C.

Dear Sir:

The tank ship CAPITAN broke in two on 24 December 1948. Through the courtesy of your office it was possible for representatives of the Ship Structure Committee to visit and survey the broken ship at Baltimore, Maryland, and also to remove samples of the fractured plating. The steel from the ship and the circumstances surrounding the failure have been analyzed by the agencies responsible for similar work on American vessels. The steel has been tested at two laboratories: The National Bureau of Standards and the American Bureau of Shipping. In accordance with a request made by your office, the Ship Structure Committee has prepared this letter which summarizes and comments on the circumstances of this failure. It should be noted that the findings and opinions presented herein are those of the Ship Structure Committee and do not necessarily represent the opinions of the member agencies.

The CAPITAN was constructed at St. Johns River Ship Building Company, Jacksonville, Florida, USA, for the U. S. Maritime Commission and is of the Commission's type T1-M-BT1. During World War II the vessel was operated by the U. S. Navy, was identified as AOG-64 and bore the name KLICKITAT.

The report shows that at the time of failure the ship was in rough sea, and that the air temperature was dropping rapidly. In twelve hours the temperature dropped from 69°F (20.5°C) at noon to 34°F (1.1°C) at midnight, the air temperature at the time of the failure being approximately 35°F (1.6°C). There were a number of contributing factors, the combined effect of which accumulated to cause the fracture. These factors have been classified and are summarized below:

1. Geometry

   a. Cracks in the half round molding on the sheer strake, apparently caused by prior damage (see 2d).

   b. Abrupt ending of the chock stool on the edge of the sheer strake in a region of stress magnification created by the termination of the amidship superstructure.

2. Materials

   a. High notch sensitivity of half round molding on sheer strake.

b. Light welds joining half round molding to sheer strake; such light welds on heavy structure are known to promote undesirable metallurgical structure.

c. Low air temperature which increased notch sensitivity in the exposed structural elements in which the crack started.

d. Prestrain caused by a previous damage at the location in question. Such prestrain of steel of the type in which the fracture originated usually results in strain ageing, which in turn promotes increased notch sensitivity.

3. <u>Loads on Critical Region</u>

a. The heavy sea produced stresses due to hogging and sagging and pounding of the vessel.

b. It is believed that the rapid drop of air temperature caused the portion of the sheer strake projecting above the deck to contract more than surrounding structure with the result that tension was produced in the top of the sheer strake.

Tests on the steel plates involved in the failure indicate that they met applicable standards of strength and ductility. At the time the steel for this vessel was purchased, notch sensitivity was not recognized as an important factor in the quality of the steel. Design details and the workmanship met the prevailing U. S. standards. The operating conditions were not abnormal at the time of the failure and we know of no action which the operating personnel of the ship could have taken to foresee the failure, or to prevent it. The failure is similar to those which have occurred in certain other vessels.

Measures are being taken on U. S. vessels to reduce the number of fractures. Such measures encompass the standards of workmanship, design, fabrication procedure and the specifications of materials. Obviously, improvements under this program apply mainly to new vessels. For this reason measures to limit the extent of damage resulting from structural failures to existing vessels were adopted in the United States. These measures usually take the form of riveted straps covering slots or the installation of riveted girders. These are intended to provide a barrier at which a propagating crack will terminate. This is admittedly only a defensive solution to the problem but our research work to date has not yielded any other remedy that is applicable to existing vessels.

A question may arise as to the extent of the injury to the structure of the vessel as a result of this failure. U. S. Surveys indicate that the damage is restricted to those plates and members which actually fracture or show gross distortion. Several U. S. vessels have broken in two, been repaired and are still giving satisfactory service.

The CAPITAN has been repaired and altered in accordance with the best prevailing U. S. practices, representative of those which, to the best of our present knowledge, should provide a reasonable safeguard against a repetition of this type of failure.

The CAPITAN failure resembles others which occurred on U. S. vessels and adds confirmation to the conclusions which the U. S. Investigating Board reported in 1946. This casualty and subsequent casualties on U. S. vessels have not indicated the need for any amendment to these conclusions. The Ship Structure Committee is indebted to the Argentine Government for the opportunity to examine the CAPITAN, thereby increasing our technical knowledge on this subject. The committee extends its acknowledgment of this courtesy.

Sincerely yours,

ELLIS REED-HILL
Rear Admiral, USCG
Chairman, Ship Structure Committee

Incls.:
- BuStds CAPITAN Report
- Final Report, Board of Investigation
- Technical Progress Report

cc: Captain Oscar J. R. Rumbo

NATIONAL BUREAU OF STANDARDS

Report

on

Investigation of Fracture in the T1 Tanker CAPITAN

By: Morgan L. Williams
Melvin R. Meyerson

INDEX

Page

NATIONAL BUREAU OF STANDARDS

Report

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PART A - ORIGIN AND PROPAGATION OF THE FRACTURE

I. Introduction

It was reported that while being towed from Savannah, Georgia to Baltimore, Maryland for reconditioning, the tanker CAPITAN broke in two at sea about midnight on 25 - 26 December, 1948. This was the first serious casualty in a vessel of this type. Both halves of the vessel remained afloat and were towed into Baltimore. This vessel, Maritime Commission type T1-M-BT1 (ex AOG64 - Klickitat), had recently been purchased by the Argentine Government.

Captain Oscar J. R. Rumbo, Naval Attache of the Argentine Embassy in Washington, graciously offered permission to the Ship Structure Committee to remove samples of the fractured material for use in the National Bureau of Standards investigation of fractures in welded ships, and also cooperated in providing information regarding the circumstances of the casualty.

Weather and sea conditions previous to and near the time of the casualty were reported as follows:

Time	Air Temp.	Water Temp.	Wind Force	Direction	Sea
1200	69°F	79	3	NW	Light
1600	63	78	5-6	NNW	Moderate
2000	46	79	7-8	N	Rough
2400	34	78	8-9	N	Rough

From the above tabulation, the air temperature at the time of the initial fracture was estimated as 35°F.

The following loading conditions were reported:

Load Liquid Cargo Tanks - Empty
Ship Stores and Fuel Oil - total 20 tons
Fresh Water - 35 tons under bridge; 20 tons in double bottom

Salt Water Ballast - Forward - Fore peak		- 50 tons
	Double Bottom, Fr 9-24	- 30 tons
Salt Water Ballast - After peak		- 12 tons
	Cofferdam - Fr 74-76	- 10 tons

II. Location and Nature of the Fracture

The bow section of the vessel (Figure 1) was examined by representatives of the Ship Structure Committee soon after its arrival at Baltimore. It was found that the fracture had originated just aft of the chock base on the port side, in the vicinity of the half-round reinforcement or scuffing bar at the top of the sheer strake.

A sample removed from this area was sent to the National Bureau of Standards for more detailed examination and for determination of the properties of the fractured plates. Two views of this sample are shown in Figure 2. The herringbone markings or chevrons on the fracture edges of the deck stringer and the sheer strake indicated that the fracture had originated at some point above the weld joining these two members. The fracture edges at the outboard side of the chock base and at the weld joining the lower part of the half round to the sheer strake were battered by contact with the deck plate of the stern section (Figures 5 and 6)and by the wire rope used for mooring (Figure 1). The exact location of the starting point of the fracture in this sample could not be determined definitely because of this battering, but it appeared to be at or near the top of the half-round.

The stern section of the vessel did not arrive at Baltimore until more than a week later, since continuing bad weather and sea conditions prevented securing a towline until after it had drifted several hundred miles farther away.

On January 7, 1949 the two sections of the vessel were examined by representatives of the Ship Structure Committee, the National Bureau of Standards, and other interested agencies. At that time two additional samples,

from the area aft of the fracture source in the port sheer strake and deck, and from E and F strakes in the port side shell, were selected for further examination. The locations of these samples, marked with white paint, are shown in Figure 3, which also shows a general view of the stern section. Another view, looking aft at the fracture, is shown in Figure 4.

On the stern section, the region of the fracture source was not battered, and it was definitely determined that the fracture started at the top of the half-round, at the location indicated by the point of the pencil in Figure 5.

The fracture was approximately perpendicular to the longitudinal axis of the vessel, and was located somewhat forward of the midship section, between oil tight bulkhead 34 and transverse frame 35 (Figures 1, 3 and 4).

In the deck, the starboard side, and the starboard part of the bottom the fracture was of the brittle or cleavage type. The plates on the lower port side and bottom and on the longitudinal centerline bulkhead, on both the bow and the stern sections (Figures 1 and 4) were bent and twisted, and showed several areas of shear type fracture and numerous longitudinal tears. This suggests that these plates were probably the last to fracture, and that the crumpling and tearing of the plates occurred during the working of the ship after the greater part of the hull girder had been broken. It was reported that the two parts of the vessel held together for about 45 minutes after the initial fracture in the deck.

The distortion of the port center deck on the stern section (Figure 4) was of a different nature, without the reverse bends, twisting, and shear type fractures. The distortion in this area appears to be a result of battering against the superstructure in the mating position on the bow section (Figure 1). The fracture edges had been battered at several other points, as may be seen in Figures 1 through 8. Some of the plates and longitudinals, especially on the deck and the port side, had been gouged or cut by violent contact with the opposite section of the vessel. An example may be seen in the upper photograph

of Figure 2, where the top longitudinal on the port sheer strake (bow section) was cut to a depth of 17 inches from the fracture edge. The width of the cut was almost exactly equal to the thickness of the sheer strake plate, and the cutout metal was curled up (on the underside of the longitudinal) in a manner similar to the chip formed by a lathe or shaper tool. The corresponding cut in the sheer strake on the stern section of the vessel may be seen in the lower foreground of Figure 5.

Part of the sample taken from the stern section in the region of the fracture source (Figure 5) is shown in Figure 6. After cleaning the fracture edges, the herringbone markings (which point toward the source of the fracture) were more clearly visible. These markings show that the fracture originated at the top of the half-round, propagated into the sheer strake through the small weld at the bottom of the half-round, and thence into the deck plate. The longitudinal fractures in the deck plate (Figure 6) and in the sheer strake just below the deck (Figures 5 and 6) resulted from battering after this initial fracture. A large indentation on the underside of the deck (Figure 6) and matching marks on the outboard side of the top of the chock (Figure 2) indicated that the deck of the stern section had over-ridden the bow section and had come down violently against the top of the chock. The fracture in the deck plate (Figure 6) originated at the top surface of the plate as a result of bending and did not progress completely to the bottom side of the plate. Similar bending type fractures were found along the inboard edge of the chock base (Figure 2). Two battered areas, about 14 inches apart on the fracture edge of the deck plate (Figure 6) fitted exactly with the battered parts on the bow section (Figure 2) at the inboard leg of the chock base and at the junction of the sheer strake and the lower edge of the half-round.

III. Evidence of Previous Deformation Near Fracture Source

It was noted also that aft of the fracture the half-round and the top

of the sheer strake were deformed as if by a blow or bump on the outboard side (Figures 5 and 6) and that the half-round forward of the fracture was bent inboard slightly (Figure 2). On first examination this appeared to be another result of the battering which occurred after the ship had fractured. However, when the two parts were fitted together, as shown in Figure 7, it could be seen that the parts of the half round forward and aft of the fracture formed a smooth curve, with the fracture about 4 inches forward of the point of maximum deformation. This shows that the deformation of the half-round must have occurred at some time previous to the fracture, since it is highly improbable that bending of the parts after the fracture could result in such a nearly perfect fit. Also, the reverse bend in the after section (to the right of the fracture in Figure 7) is obviously a result of restraint imposed by the section forward of the location of the fracture.

The deformation of the sheer strake is shown in Figure 8 by cross sections of the half-round, sheer strake, and deck stringer taken at locations about 9 inches forward and 4 inches aft of point S in Figure 7. The section from forward of the fracture (Figure 8, right) shows the sheer strake nearly perpendicular to the deck plate, with only slight deformation. The bottom of the half-round had separated slightly from the sheer strake, and a small crack is visible in the weld (arrow).

The section from aft of the fracture (left, Figure 8), which was taken near the point of greatest deformation, shows the sheer strake bent inboard above the deck. The deck plate was bent downward slightly at this point as a result of the battering which caused the longitudinal fracture in the sheer strake just below the deck plate (Figure 5). A small crack in the weld joining the sheer strake and the deck stringer is indicated by the arrow.

The inward displacement of the parts above the deck plate was about equal to the thickness of the half-round. This, together with the shape of the

indentation (Figure 7), indicates that the deformation resulted from contact of the half-round (which projected outboard from the side of the ship) with some object such as a mooring post, fender, or pile.

IV. Origin of the Fracture

A view of the region of the fracture source, looking from outboard and slightly above, is shown in Figure 9. V-shaped pieces for metallographic examination had been cut out at C, just aft of the fracture in the sheer strake, and at A-B in the half-round forward of the fracture. The fracture source S was about an inch forward of the weld W at the after end of the chock base. Part of the chock base had been lost as a result of battering, and the fractures in the weld at W and at the top of the half-round were also battered and abraded.

Some small depressions, filled with corrosion products, were observed in the top of the half-round just aft of the fracture source, at the points indicated by S and E in Figures 7 and 9. Another V-shaped section was cut from this area, as shown at D in Figure 10, and three cracks, extending approximately vertically downward into the half-round, were found at points E, F, and S. The "depressions" were the result of corrosion at the top edges of these cracks, and the extent of this corrosion indicated that the cracks had existed for a considerable length of time.

Crack E, near the after corner of the chock base, was approximately parallel to the length of the half-round, and cracks F and S, farther forward, were inclined at increasing angles from the longitudinal axis. Crack S, which eventually became the source of the catastrophic fracture, was inclined at about a 45 degree angle, and was nearly parallel to the final fracture.

The section removed from the top of the half-round at area D in Figure 10 was polished and etched on both of the sawed surfaces. Examination of the etched surfaces revealed that cracks E and F both started in the overlapping heat-affected zones between two weld beads which were close together but not

joined. The surface adjoining D-E in Figure 10 (looking in the opposite direction) is shown in Figure 11. Crack E, at the top of the specimen, originated between the weld joining the half-round to the sheer strake (top right) and the weld joining the chock base to the half-round (top left). Another small crack may be seen at the outboard (left) edge of the latter weld. The crack at the bottom in Figure 11 is a part of crack F (Figure 10) which originated between these same welds farther forward, and propagated aft and inboard overlapping but not joining crack E.

After completion of the hardness measurements shown in Figure 11 (which will be discussed later) the specimen was broken apart to expose the surfaces of the cracks. These surfaces, although somewhat corroded, showed the characteristic markings of a brittle fracture. There was no indication that the cracks had originated or propagated as a result of fatigue.

It is evident that these cracks occurred as a result of the restraint imposed by the after corner of the chock base at the time of the deformation of the half-round and sheer strake. As previously noted, the cracks overlapped but were not joined, and the angles between the longitudinal vertical plane and the cracks (E, F and S) increased with increasing distance forward from the after corner of the chock base. This indicates that the cracks occurred successively as the deformation increased, and suggests that the deformation may have been a result of a number of slight bumps rather than a single severe impact.

The fact that the cracks did not propagate further at that time may be attributed to one or more of the following factors:

1. When the deformation occurred, the temperature may have been relatively high, resulting in decreased notch sensitivity and greater ductility of the steel. Therefore the cracks propagated only in the excessively brittle region created by the heat-affected zones of the two welds.

2. The deformation resulted from transient and localized stresses of short duration, and propagation of the cracks may have occurred only during the short period of maximum intensity of these stresses.
3. Loading and sea conditions at the time of formation of the cracks (and up to the time of the casualty) did not impose stresses of sufficient severity to cause propagation of the cracks.
4. The cracks were more or less parallel to the direction of principal stress (longitudinal), and thus did not cause as severe a stress concentration as would be the case if they had been more nearly perpendicular to the longitudinal direction.

However, the cracks did form potential stress raisers, at a critical location in the structure of the vessel. Forward of this location (Figure 1) the hull girder was stiffened by the chock base, the raised sides of the forecastle, and the deck superstructure extending aft to frame 34. The abrupt termination of these stiffeners at the after end of the chock base constituted a structural notch almost exactly at the location of the cracks. The deformation of the half-round and the sheer strake had probably caused some residual tensile stresses in this area. The notch sensitivity of the steel had been increased in the heat-affected zone near the welds connecting the half-round to the sheer strake and the chock base, and was probably further increased as a result of strain ageing subsequent to the deformation.

The combination of these factors created a condition favorable to the initiation of a fracture at this point. At the time of the casualty, the following additional factors contributed to the failure:

1. Low air temperature (35°F) increased the notch sensitivity of the steel.
2. The rapid drop of the air temperature (from 63°F to 35°F in the 7

hours preceding the casualty) and the differential between the air temperature (35°F) and the water temperature (78°F), would cause unequal thermal contraction in various parts of the hull structure. This would result in tensile stresses in the half-round and the top of the sheer strake, since these parts, completely exposed to the cold air, would be colder than the deck and the side plating, which were exposed on one side to the warm interior of the ship, and were also warmed by conduction from the warm water. These stresses would be additional to those resulting from the loading of the vessel.

3. The rough seas and strong winds at the time of the casualty caused varying tensile, compression, and torsional stresses as a result of the pitching of the vessel, shifting of the center of buoyancy, and changing wind and wave pressures on different parts of the ship. These dynamic forces undoubtedly produced intermittent peaks of tensile and torsional stresses at the location of the fracture source.

The critical stress necessary to cause rapid propagation of the previously existing crack was lowered by the factors leading to stress concentration and increased notch sensitivity at that point. This reduced critical stress was exceeded by the combination of the peak dynamic stresses resulting from the weather and sea conditions and the more or less static tensile stresses previously enumerated.

V. <u>Examination of Welds</u>

The cross sections of the deck plate, sheer strake, and half-round, shown in Figure 8, were polished and etched to determine the size and quality of the welds in the vicinity of the fracture source.

The welds joining the deck plate to the sheer strake were somewhat below average quality, since they did not penetrate the joint completely, and contained a number of slag inclusions. However, such defects are rather common

in ship construction, and these welds did not contribute to the failure.

The half-round was connected to the sheer strake by small shallow welds, with very little penetration into the base metal. Only a small amount of weld metal was deposited especially in the joint at the top of the sheer strake. Although these welds were probably adequate in strength, the use of such small welds on heavy material is a potentially dangerous practice. The small heat input associated with a small shallow weld does not heat the surrounding base metal appreciably, and consequently the heated zone near the weld is cooled very rapidly by conduction to the mass of cold metal. This amounts, in effect, to a very drastic quench, and the result is a hard, extremely notch sensitive area, a "metallurgical notch".

Several small brackets (Figure 7) were joined to the deck by similar small shallow welds, as shown at the left in Figure 8. These resemble the weld attaching a clip to the deck, which was one of the primary factors leading to the failure of a T2 tanker about a year previously. In that casualty, as in the CAPITAN, the fracture originated near the end of a chock base, and at a point where two welds (one of which was small and shallow) were so close together that the heat-affected zones overlapped.

The weld joining the chock base to the top of the half-round and the sheer strake was made from the outboard side only, and was laid on top of the previously completed weld connecting the half-round to the sheer strake. At a point 10 inches forward of the after corner of the chock base, shown at the upper right in Figure 8, the weld did not penetrate the joint completely, resulting in a poor bond to the top of the sheer strake, which apparently had been flame cut. The sheer strake was buckled slightly, and, as may be seen in Figures 8 and 10, the chock base did not fit exactly flush with the top of the sheer strake at all points. In Figure 10, the shape and position of the welds W

and the small tack weld on the inboard half of the sheer strake (to the left of the letter D) indicate that the after corner of the chock base was displaced outboard, with relation to the sheer strake, by almost half the plate thickness. As a result of this misalignment, the weld at the outer side of the chock base was on the half-round, outboard of the weld joining the half-round to the sheer strake. Because of the poor penetration of the chock base weld, the two welds were not joined, and the after corner of the chock base was not connected directly to the sheer strake except by the small tack welds. Consequently, when the deformation of the half-round and sheer strake occurred, the restraint of the chock base was exerted almost entirely on the outer weld on the half-round. Cracks which became the source of the final fracture were formed in the overlapping heat-affected zones of the two welds, as shown in Figure 11 and discussed in the preceding section of this report.

PART B. - PROPERTIES OF THE HALF-ROUND AND PLATES NEAR THE FRACTURE SOURCE

VI. Hardness Surveys

Hardness surveys were made on the section removed from the top of the half-round near the fracture source (at D, Figure 10) and at selected areas on the cross sections from forward and aft of the fracture (Figure 8).

The section from near the fracture source is shown in Figure 11, with the Diamond Pyramid Hardness numbers (20 Kg load) indicated under the corresponding indentations, which were spaced 1 mm apart. (Values which were obviously erroneous due to cracks, corrosion, or unsupported edges near the indentation are indicated by the letter X). These data show that the metal of the half-round was hardened to a considerable degree in the heat-affected zones (lighter areas) under the two welds at the top, and that this hardening extended for some distance from the welds. The effect of the overlapping heat-affected zones could not be determined on this sample because of the cracking and

corrosion in this area. The hardness number 238, near the top of the crack, is probably too low, since a corrosion pit was found immediately under the indentation when the specimen was broken for examination of the crack.

The average hardness values at comparable locations on the two cross sections shown in Figure 8 are given in Table I.

Vickers Diamond Pyramid Hardness Numbers (20 Kg load)

Location		Deformed Section Aft of Fracture	Straight Section Fwd of Fracture	Difference
Half Round				
Near bottom	1/8" from flat	164	143	21
Near top	inboard side	178	141	37
Outboard	1/4" from round edge	186	146	40
Weld Metal				
Bottom of half-round		218	199	19
Top of half-round		241	192	49
Sheer strake - near top of deck				
Near center of plate thickness		170	158	12
Near outboard plate surface		185	151	34

In the deformed section from aft of the fracture, the average hardness at each location was greater than the average hardness at the corresponding area in the relatively undeformed section from forward of the fracture. In the straight section, the hardness was nearly the same at the three locations on the half-round, but in the deformed section the areas near the top and the outboard side of the half-round were harder than the area near the bottom. A similar relation is seen in the hardness of the welds joining the half-round to the sheer strake. The weld at the top in the deformed section, was harder and showed greater increase of hardness than the weld at the bottom. This difference in the hardness relations of the weld metal could be attributed in part to differences in the size of the welds and to the effect of the chock base weld at the top of the undeformed section.

However, the hardness differences in the half-round itself were evidently a result of the deformation, or of strain aging subsequent to the deformation. The area near the bottom of the half-round was nearer to the neutral axis of the longitudinal bend (Figure 7) and was deformed to a lesser extent because of the inward bending of the sheer strake (Figure 8). Hence this area, which showed the least increase of hardness in the deformed section, was less severely deformed than the areas at the top and at the outboard side of the half-round, which showed greater hardening in both the half-round and the weld metal. The hardness measurements on the sheer strake (Table I) also show that the hardening effect increased with increasing deformation.

The section from the top of the half-round near the fracture source (Figure 11) was considerably harder, even at some distance from the welds, than the corresponding areas on the sections from forward and aft of the fracture (Table I). This indicates that the area near the fracture source was very severely deformed, probably as a result of the restraint imposed by the chock base.

It has been reported previously[1] that in a number of steels of the types used in ship construction, the notch sensitivity was increased by deformation, and that the increase of notch sensitivity was greater with increasing severity of the deformation. If the same relation holds true for the metal of the half-round, it is evident that the notch sensitivity in the area of the fracture source was greatly increased as a result of the deformation which occurred at some time previous to the casualty.

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(1) Progress Summary on Investigation of Fractured Steel Plates Removed from Welded Ships, by Morgan L. Williams and George A. Ellinger. Ship Structure Committee Report No. NBS 1, dated February 25, 1949. Page 33.

VII. Tensile Properties

The tensile properties of the half-round, in which the fracture originated, and of four plates selected from the area near the fracture, are given in Table 2.

Standard 8 inch gage length tensile specimens could not be obtained from some of the samples because of the limitations imposed by sample size, surface corrosion, and the location of welds or deformed areas which might affect the properties. Consequently various types and sizes of specimens were used, as shown in the fourth column of the table. The data in the table represent, in most cases, average values for duplicate specimens. Additional tensile tests were made on some of the plates, using specimens taken from different areas of the samples or specimens of different sizes or types, as indicated in the second and fourth columns of Table 2.

Specimens taken from deformed areas of the plates did not show a definite "drop of needle" at the yield point, but the tensile strength and elongation were nearly the same as for undeformed specimens.

For specimens taken adjacent to the seam or butt welds in the deck plate and plates E7 and F7 port, the yield point, tensile strength, and yield/tensile ratio were higher, and the percentage elongation was somewhat lower, than for similar specimens taken from interior areas of the respective plates. The tensile strength, yield point, and yield/tensile ratio were still higher for specimens taken from the seam weld (apparently a submerged-melt weld) between plates E7 and F7.

The tensile properties of all of the samples tested indicate that the material met the requirements of the American Bureau of Shipping specification for hull steel which was in effect at the time the ship was built. The material would also meet the requirements of the current (1948) American Bureau of Shipping specification for tensile properties.

VIII. Notched-Bar Impact Properties

Standard Charpy V-notch specimens, notched perpendicular to the plate surface (or the flat surface of the half-round) were tested at various temperatures in a pendulum type Charpy impact machine of 224 foot pounds capacity, with a striking velocity of 16.85 feet per second. A summary of the notched-bar test data for longitudinal specimens is given in Table 3.

Specimens from the half-round were taken from the deformed area just aft of the fracture (Figures 6 and 7) and from the relatively straight undeformed area farther aft. The transition temperature for the specimens from the straight area was 100°F, indicating rather high notch sensitivity.

For specimens from the deformed area, the transition temperature was higher, 110°F, and the average energy absorption at the various test temperatures was lower, as shown, for certain temperatures, in Table 3. Comparison of the energy absorption of individual specimens (giving due consideration to the effects of the testing temperatures, the location of each specimen with respect to the deformation, and the proximity of some specimens to the welds at the top and bottom of the half-round) showed that the decrease of energy absorption was greater in the areas of greatest deformation. This indicates that the notch sensitivity of the steel had been increased as a result of the deformation which had occurred at some time previous to the casualty, and that the amount of the increase was dependent on the severity of the deformation. The results of these tests confirm the interpretation of the hardness surveys discussed in Section VI, and indicate that the rather high inherent notch sensitivity of the half-round was greatly increased in the area near the fracture source, since the hardness surveys showed that the deformation was more severe in this area.

The transition temperature of the specimens from the port sheer strake was considerably lower than the average for ship plates tested previously, and the energy absorption, even at the low air temperature of 35°F, was com-

paratively high. The relatively low notch sensitivity of this plate probably contributed to the delay in the propagation of the fracture on the port side of the vessel.

The deck stringer showed a transition temperature near the average of the range previously found for plates of this thickness which fractured completely through but did not contain a source nor an end of a fracture.

Specimens from port side plates E7 and F7 showed transition temperatures somewhat higher than the average for plates less than 3/4" thick in the "fracture thru" group. However, these plates were probably submerged periodically as a result of wave action, and consequently their temperature would be near that of the water (78°F). At this higher temperature, the energy absorption, especially of plate E7, was relatively high, which probably also contributed to the delay of the propagation of the fracture.

It is also possible that the notch sensitivity of these plates, in the area where the test specimens were taken, was increased as a result of straining during the working of the ship after the initial fracture. In plate E7, the longitudinal specimens were taken a short distance aft of the visibly deformed area near the fracture. A few transverse specimens, taken from a location farther aft, showed a lower transition temperature than the longitudinal specimens, whereas usually in a steel of this type the transition temperature of the longitudinal specimens is lower.

IX. Chemical Compositions of the Steels

The chemical compositions of the steels are shown in Table 4, and for two of the steels, the total contents of oxygen, nitrogen, and hydrogen, as determined by the vacuum-fusion method, are given in the following table.

Table 5. Gas Analyses, Vacuum-Fusion Method

Sample	% O_2	% N_2	% H_2
Half-Round	$.007_2$	$.007_2$	$.001_9$
Sheer Strake	$.009_1$	$.004_0$	$.002_3$

The steel of the half-round was relatively high in phosphorus, sulfur, nitrogen, and aluminum, and low in silicon. This composition suggests that the material could be a Bessemer steel. The maganese/carbon ratio of this steel was also higher than the average for plates tested previously.

The chemical compositions of the four plates were within the range usually found for steels of this type.

X. Metallographic Examination of the Steels and Weld Zones

Metallographic examinations of samples taken from the top of the sheer strake and the half-round (at the locations shown in Figure 9) revealed the typical microstructure of pearlite in a ferrite matrix, with normal inclusions. The grain size of the half-round was #6, and of the sheer strake #5 and #6. The weld metal had a very fine grain, and low carbon content. The heat-affected zones near the weld at the top of the half-round and the sheer strake were normal, showing large grains next to the weld, gradually becoming smaller and blending into the base structure.

The specimens were taken at points about an inch from the fractures in the half-round and the sheer strake, in order to preserve the fracture surfaces intact. No secondary cracks or Neumann bands were found in the metal of the half-round or the sheer strake at this distance from the fracture. Some small cracks were found in the weld metal at the top of the specimens, and the grains in the area showed evidence of deformation by tension and by battering.

XI. Acknowledgements

The samples of fractured material, and information regarding the circumstances of the casualty, were made available for use in this investigation through the courtesy of Captain Oscar J. R. Rumbo, Naval Attache of the Argentine Embassy, whose cooperation is greatly appreciated.

Mr. Gordon L. Kluge and Mr. Leo. R. Dale cooperated in the preparation of the specimens and the determination of the mechanical properties.

The chemical compositions were determined by the analytical chemistry and spectroscopy sections of the National Bureau of Standards, and the gas analyses were conducted by Mr. James T. Sterling of the chemical metallurgy section.

PART C - SUMMARY AND CONCLUSIONS

XII. Summary

The T1 tanker CAPITAN broke in two while being towed during a storm at sea. At the time of the casualty the air temperature was 35°F, the water temperature 78°F, the wind force 8-9, and the sea rough.

The fracture in the deck, the starboard side and the starboard part of the bottom was of the brittle cleavage type. On the lower port side and bottom and the longitudinal centerline bulkhead, there was several areas of shear fracture, and the plates were crumpled and twisted, which indicates that these were the plates which held the ship together for 45 minutes after the initial fracture was found in the deck, as reported by members of the crew.

Representatives of the Ship Structure Committee found, by examination of the fracture edges, that the fracture originated in the half-round reinforcement or scuffing bar on the outboard side of the port sheer strake, near the after corner of a chock base. Samples from this area, forward and aft of the fracture, and from the port side plating, were selected for more detailed examination and for determination of the properties of the fractured plates.

When the parts from forward and aft of the fracture were fitted together, it was found that the half-round and the sheer strake above the deck had been deformed at some time before the fracture, apparently by striking some object on the outboard side, just aft of the chock base. As a result of this deformation and the restraint imposed by the after corner of the chock base, small cracks were formed at the top of the half-round, in the overlapping heat-affected zones of two welds.

The welds joining the half-round to the top of the sheer strake and the chock base to the half-round were not properly joined because of poor penetration of the latter weld and a slight misalignment of the chock base at this point. Both welds were small and shallow, a condition which, on heavy plate, may cause a "metallurgical notch" as a result of the low heat input associated with such welds and the consequent rapid cooling of the heat-affected zone by conduction to the surrounding mass of cold metal.

The top parts of the cracks were badly corroded, indicating that they had existed for some time before the casualty. The surfaces of the cracks showed the characteristic markings of a brittle fracture, and there was no indication of fatigue.

These cracks did not propagate until a critical combination of notch sensitivity, static stresses, and dynamic stresses was reached. However, they did form potential stress raisers at a point where a structural notch existed because of the stiffening effect of the chock base and super structure forward of this location, and one of these cracks became the source of the catastrophic fracture.

Notched bar tests and hardness measurements showed that the metal of the half-round was notch sensitive, and that the notch sensitivity at that point was increased as a result of the welds and the previous deformation, or strain aging subsequent to the deformation. Low air temperatures at the time

of the casualty caused a further increase of notch sensitivity.

At the time of the casualty, the following factors contributed to the stress at the point of origin of the fracture:

1. Residual stress resulting from the deformation of the half-round.
2. Unequal thermal contraction because of the rapid drop of the air temperature and the differential between the air and water tenperatures.
3. The bending moment produced by the conditions of loading.
4. Dynamic and inertia forces resulting from wind and wave action and the pitching of the vessel.

Samples of steel from the half-round and from four plates near the origin of the fracture were selected for determination of the mechanical properties, chemical compositions, and metallographic features.

The tensile properties of the samples complied with the requirements of the current (1948) American Bureau of Shipping specification for hull steel, as well as the requirements of the specification which was in effect at the time the ship was built.

Tensile specimens taken near the welds showed higher yield points, tensile strengths, and yield/tensile ratios, and somewhat lower elongations than similar specimens taken from the interior of the respective plates.

The steel of the half-round was inherently more notch sensitive than the average for ship plates. The notch sensitivity was further increased as a result of the small shallow welds and of the deformation which had occurred at some time previous to the casualty. In the area near the fracture source, hardness surveys showed that the deformation was especially severe, which would cause greatly increased notch sensitivity.

The transition temperatures of Charpy V-notch specimens from the deck stringer and port side plates E7 and F7 were about average. However, the energy

absorption of the two portside plates was reasonably high at the water temperature reported at the time of the casualty.

The notch sensitivity of the port sheer strake plate was relatively low, and this, together with the effect of the higher water temperature, probably contributed to the delay of the propagation of the fracture on the port side of the vessel.

The chemical composition and nitrogen content of the half-round suggest that the material could be a Bessemer steel.

The chemical compositions of the four plates were within the range usually found for steels of this type.

The microstructures of the half-round, the sheer strake, and the weld joining these members were normal.

XIII. Conclusions

It is evident that a number of factors contributed to this casualty, and that no single factor, by itself, was sufficient to cause the failure. The structural notch resulting from the stiffening effect of the chock base and the forward superstructure, which terminated abruptly at the after end of the chock base, was present in all vessels of this type. Undoubtedly some of these vessels had encountered similar weather, sea, and loading conditions, and there had been no serious casualties. The inherent notch sensitivity of the half-round, and the increased notch sensitivity (or metallurgical notch) resulting from the adjoining small shallow welds at the after corner of the chock base had probably been present for the entire life of the vessel. The deformation of the half-round at this critical location, and the resulting increased notch sensitivity, residual stresses, and cracks, apparently had existed for a considerable time. (The minor nature, and the location of the deformation were such that it would probably be passed over in even the most careful inspection). These cracks did not propagate further, however, until weather, sea, and loading conditions

combined with the above factors to cause a critical combination of notch sensitivity, stress concentration, and static and dynamic stresses.

Many of these same factors have been observed in previous casualties involving ships of other types, and in view of these observations the following preventive measures are suggested:

1. Steel which is notch sensitive or subject to excessive strain aging should not be used even for non-strength members attached to the hull structure by welding, since cracks originating in such members may propagate into the hull structure through the welds.
2. In future construction, small welds to heavy plate should be avoided unless adequate precautions are taken, such as preheating. The possibilities of low temperature brazing or other methods of joining for small, lightly loaded attachments such as clips, should be investigated.
3. Adjacent welds, other than those occuring in tee and lap joints, should not be placed so that a notch is formed between them, since even a minor mechanical notch superimposed on a metallurgical notch resulting from the welds may cause serious stress concentration.

Table 2. Tensile Properties of Longitudinal (L) and Transverse (T) Specimens, S. S. CAPITAN

Plate No.	Description of Plate	Plate Thickness	Size of Specimens		Yield Point (Needle Drop)		Tensile Strength		Elongation - Gage Length		Reduction of Area		Ratio Yield/Tensile		Remarks
		t	L	T	L	T	L	T	Longitudinal	Transverse	L	T	L	T	
		Inches	Inches	Inches	PSI	PSI	PSI	PSI	% Inches	% Inches	%	%	%	%	
61 A	Half Round	1 1/2 x 3	.505d	-	38600	-	68600	-	33.0 - 2.0	- -	61.5	-	56.3	-	Specimens from 20 inches aft of fracture.
61 B	Sheer Strake, Port	0.68	1.5xt	-	31800	-	60000	-	26.6 - 8.0	- -	-	-	53.0	-	Standard 8" gage length specimens.
	" "		.505d	.505d	32000	32000	62300	61600	36.0 - 2.0	32.5 - 2.0	64.5	57.5	51.4	52.0	Standard .505" diameter specimens.
61 C	Deck Stringer, Port	0.87	.505d	-	32800*	-	65500	-	33.0 - 2.0	- -	58.6	-	50.7*	-	
	" " Bent Area		-	.505d	-	-**	-	66600	- -	30.5 - 2.0	-	51.6	-	-**	**No definite yield. Specimens deformed slightly.
	" " Near Butt Weld		-	.505d	-	42000	-	68300	- -	26.3 - 2.0	-	50.8	-	61.5	Specimens near and parallel to butt weld.
61 D	E 7 Port	0.50	3/4xt	-	33900	-	60600	-	39.5 - 2.0	- -	48.5	-	56.0	-	Flat 2" gage length specimens.
	" "		.357d	.357d	34600	40100x	61500	63100	36.4 - 1.4	35.4 - 1.4	65.5	59.2	56.3	63.5x	xTransverse specimens near deformed area.
	" " Near seam weld		.357d	-	42100*	-	66300	-	31.4 - 1.4	- -	67.7	-	63.2*	-	Specimens near and parallel to seam weld.
61 E	F 7 Port	0.58	1.5xt	1.5xt	32600	30400	60000	58500	24.0 - 8.0	25.0 - 8.0	51.0	47.0	54.3	52.0	Standard 8" gage length specimens.
	" "		.357d	.357d	34900	32800	63900	63200	34.3 - 1.4	32.8 - 1.4	61.9	56.5	54.6	51.9	Subsize round specimens.
	" " Near seam weld		.357d	-	43800*	-	67600	-	29.3 - 1.4	- -	61.1	-	65.0*	-	Specimens near and parallel to seam weld.
61 W	Seam Weld E 7 - F 7	-	.357d	-	48800*	-	69900	-	29.3 - 1.4	- -	65.5	-	70.3*	-	Specimens in weld metal parallel to length of machine-welded seam.

t = Plate thickness
d = diameter of round specimens.
* No definite yield point on one of two specimens.

Table 3. Notched Bar Test Data

(Longitudinal Charpy V-notch Specimens, Notched Perpendicular to Plate Surfaces).

Plate No	Description of Plate	Plate Thickness Inches	Failure Temp °F(1)	15 Ft.Lb Transition Temp °F(2)	Energy Absorbed-Ft.Lb.		
					At 70°F	At 30°F	At Failure Temperature
61 A	Half Round	1 1/2x3					
	Straight Area		35 A	100	10.0	7.8	8.1
	Deformed Area		35 A	110	9.0	7.3	7.5
61 B	Sheer Strake	0.68	35 A	38	35.0	10.9	13.4
61 C	Deck Stringer	0.87	35 A	72	13.3	6.5	7.5
61 D	E 7-Port(3)	0.50	78 W	70	14.9	6.2	18.7
61 E	F 7-Port	0.58	78 W	85	9.3	5.2	11.5

(1) A = air temperature at time of failure, W = water temperature.

(2) Defined as the temperature at which, for a given plate, the notched bar test curve (average energy absorbed by standard longitudinal, notch - perpendicular, Charpy V notch specimens vs. temperature of test) crosses the line of 15 foot pounds energy absorption.

(3) The longitudinal specimens were taken from near a deformed area of the plate, and the notch sensitivity in this area may have been increased as a result of previous strain. Transverse specimens, from a location farther from the deformation, showed a lower transition temperature and higher energy absorption.

Table 4. - Chemical Compositions of the Steels

Plate Identification / Composition %	61A Half Round	61B Sheer Strake	61C Deck Stringer	61D E7 Port	61E F7 Port
Carbon	0.22	0.23	0.26	0.22	0.22
Manganese	.59	.52	.45	.45	.42
Phosphorus	.081	.005	.012	.005	.011
Sulfur	.041	.030	.027	.030	.020
*Silicon	.016	.094	.066	.070	.053
*Copper	.006	.056	.096	.05	.03
*Nickel	.006	.024	.050	.02	.03
*Chromium	.002	.019	.043	.02	<.02
*Vanadium	.004	<.004	<.004	<.01	<.01
*Molybdenum	<.003	.005	.006	<.01	<.01
*Aluminum	.031	<.005	<.005	.008	.008
*Titanium	<.009	<.009	<.009	<.01	<.01
*Arsenic	<.02	<.02	<.02	<.02	<.02
*Tin	<.003	.006	.006	—	—
Ratio %Mn/%C	2.68	2.26	1.73	2.04	1.91

* Spectrochemical analysis.

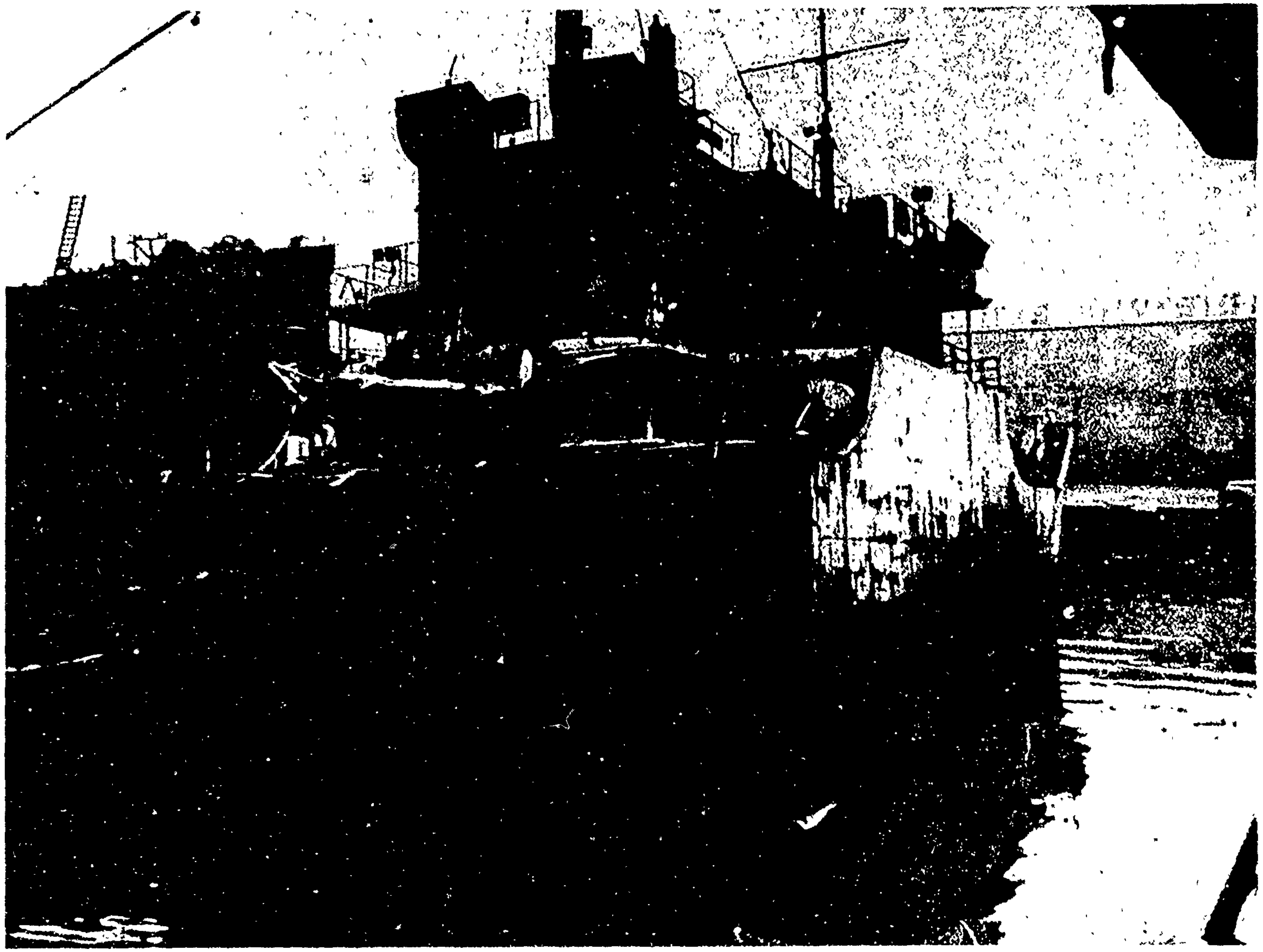

Fig. 1. Bow section of T1 tanker CAPITAN, showing location of fracture just aft of oil tight bulkhead 34. The starting point of the fracture was near the chock on the port side (left).
U. S. Coast Guard Photograph

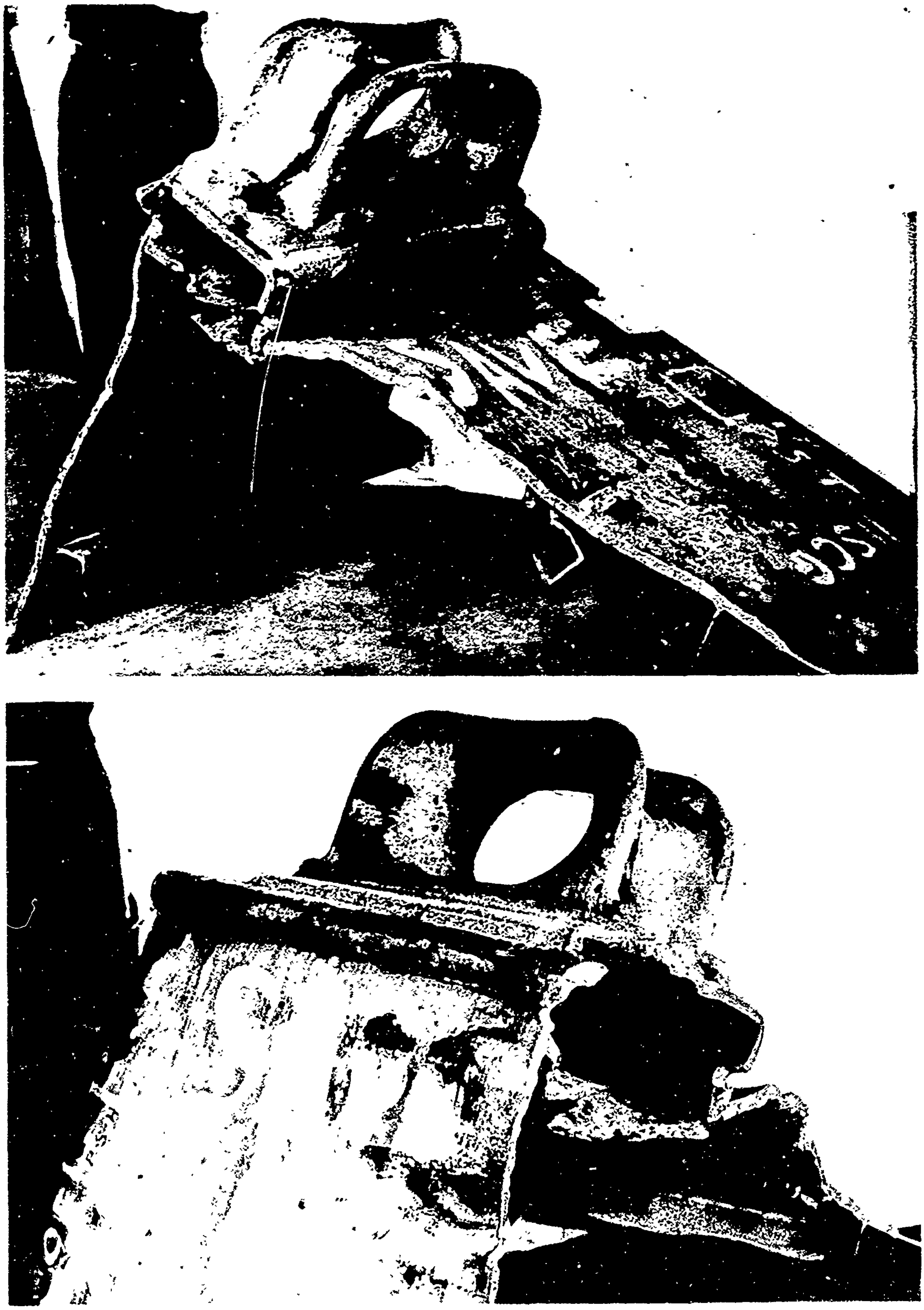

Fig. 2. Two views of sample removed from bow section, port side. Note the slight inward bend of the half round near the fracture (under near corner of chock, lower photograph) and the battered condition of the chock base, deck plate and longitudinals.

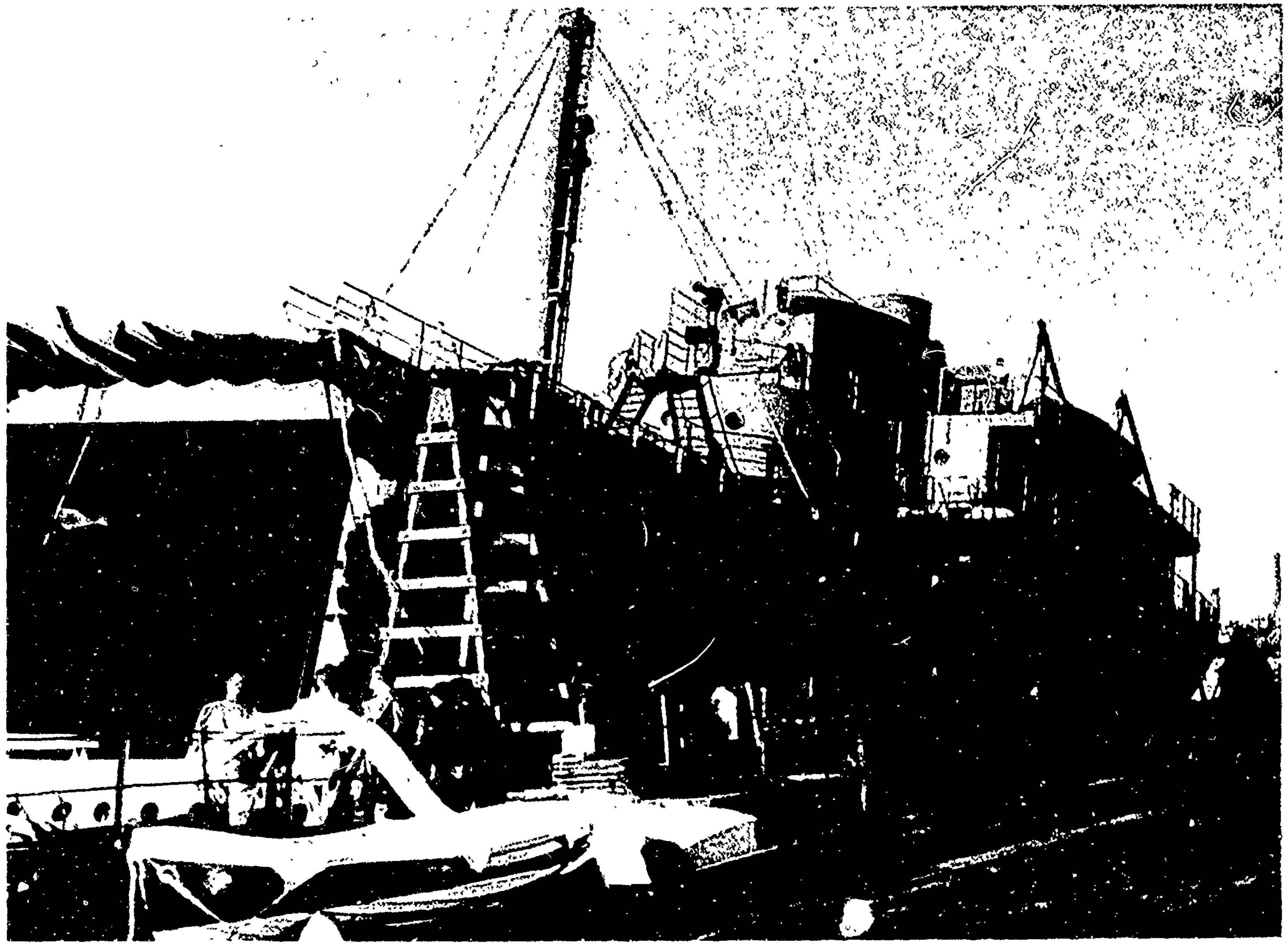

Fig. 3. General view of stern section, port side, looking aft. Samples selected for examination are marked with white painted lines and symbols (above group of men in foreground and at top of sheer strake near fracture).

Photographed by Captain Oscar J. R. Rumbo, Argentine Naval Attache.

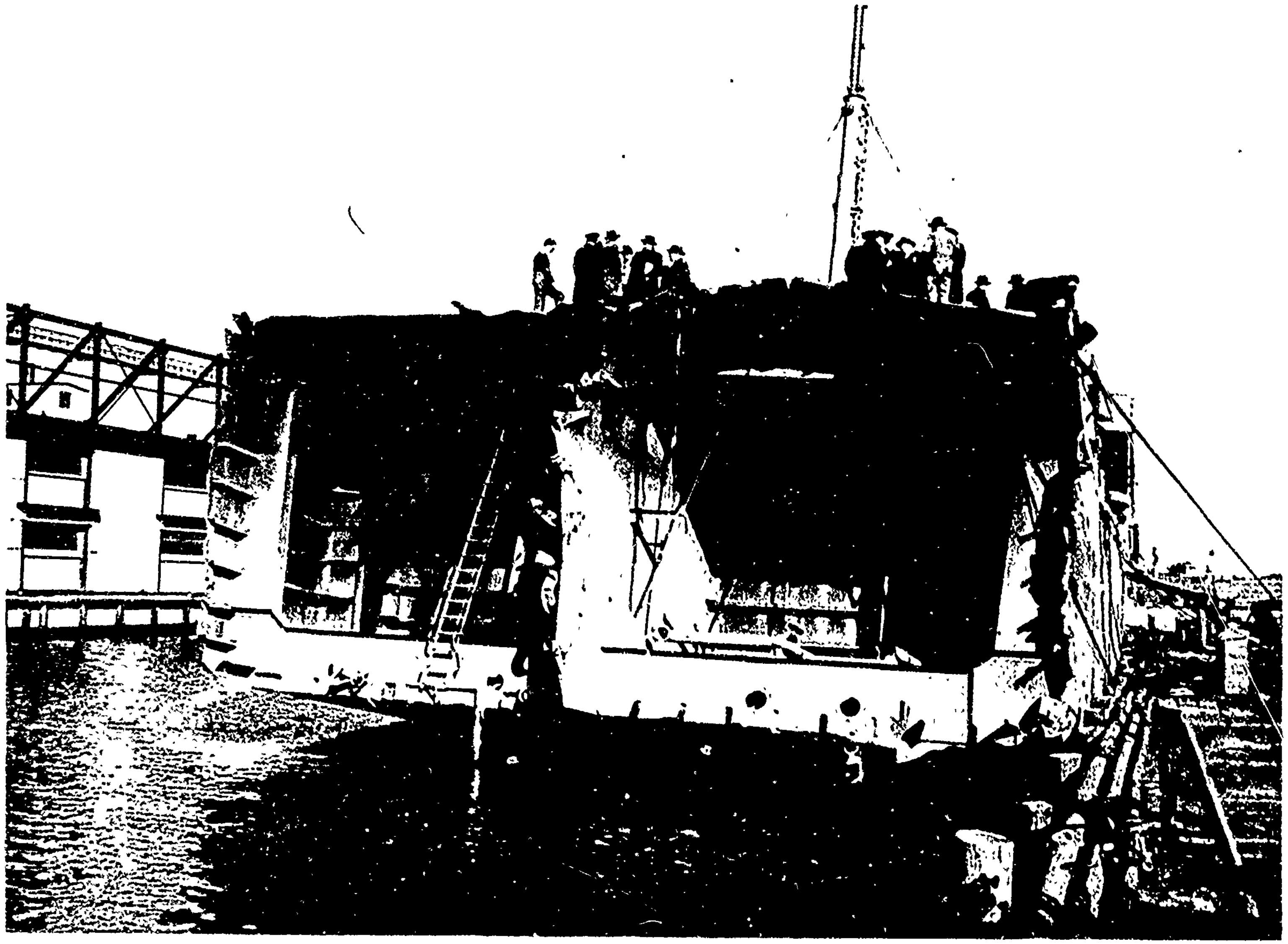

Fig. 4. Stern Section showing fracture just forward of frame 35. Note battered condition of plating on port side (right) and centerline bulkhead. The man leaning over the side is examining source of the fracture.

U. S. Coast Guard Photograph.

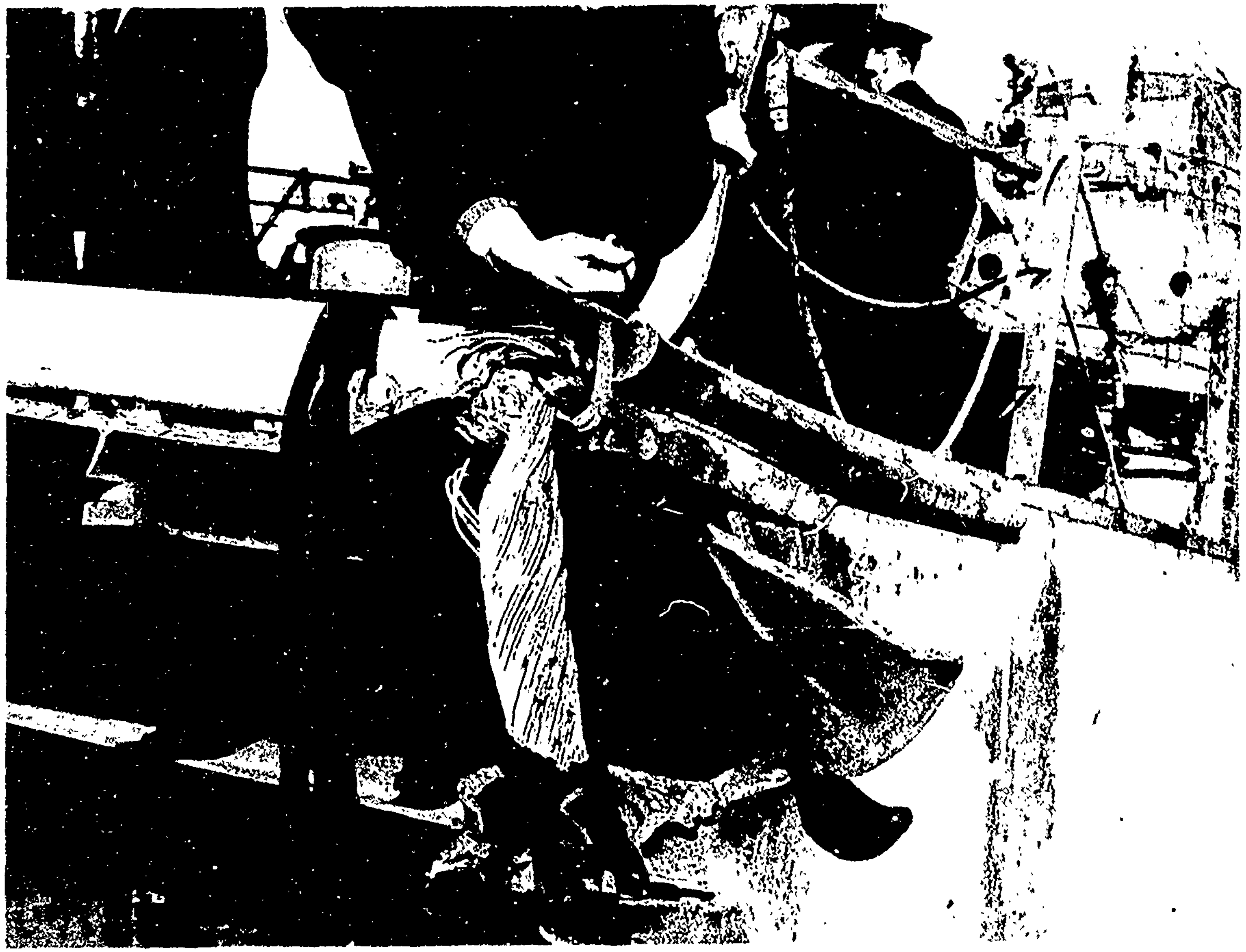

Fig. 5. Starting point of the fracture (indicated by pencil) at top of half round reinforcement on upper edge of sheet strake. Stern section, looking inboard and aft. Note the bend in the half round, just aft of the fracture.
U. S. Coast Guard Photograph.

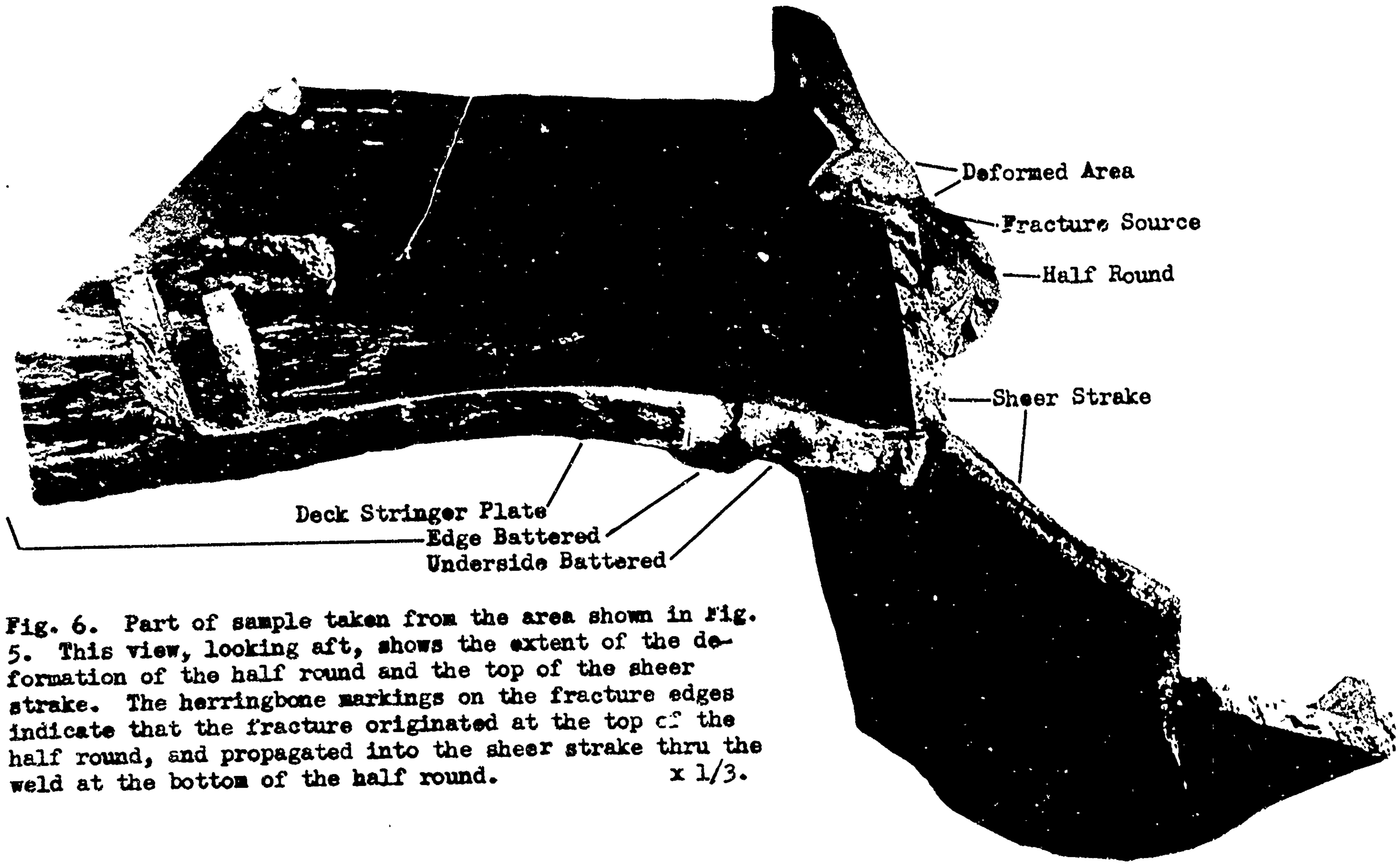

Fig. 6. Part of sample taken from the area shown in Fig. 5. This view, looking aft, shows the extent of the deformation of the half round and the top of the sheer strake. The herringbone markings on the fracture edges indicate that the fracture originated at the top of the half round, and propagated into the sheer strake thru the weld at the bottom of the half round. x 1/3.

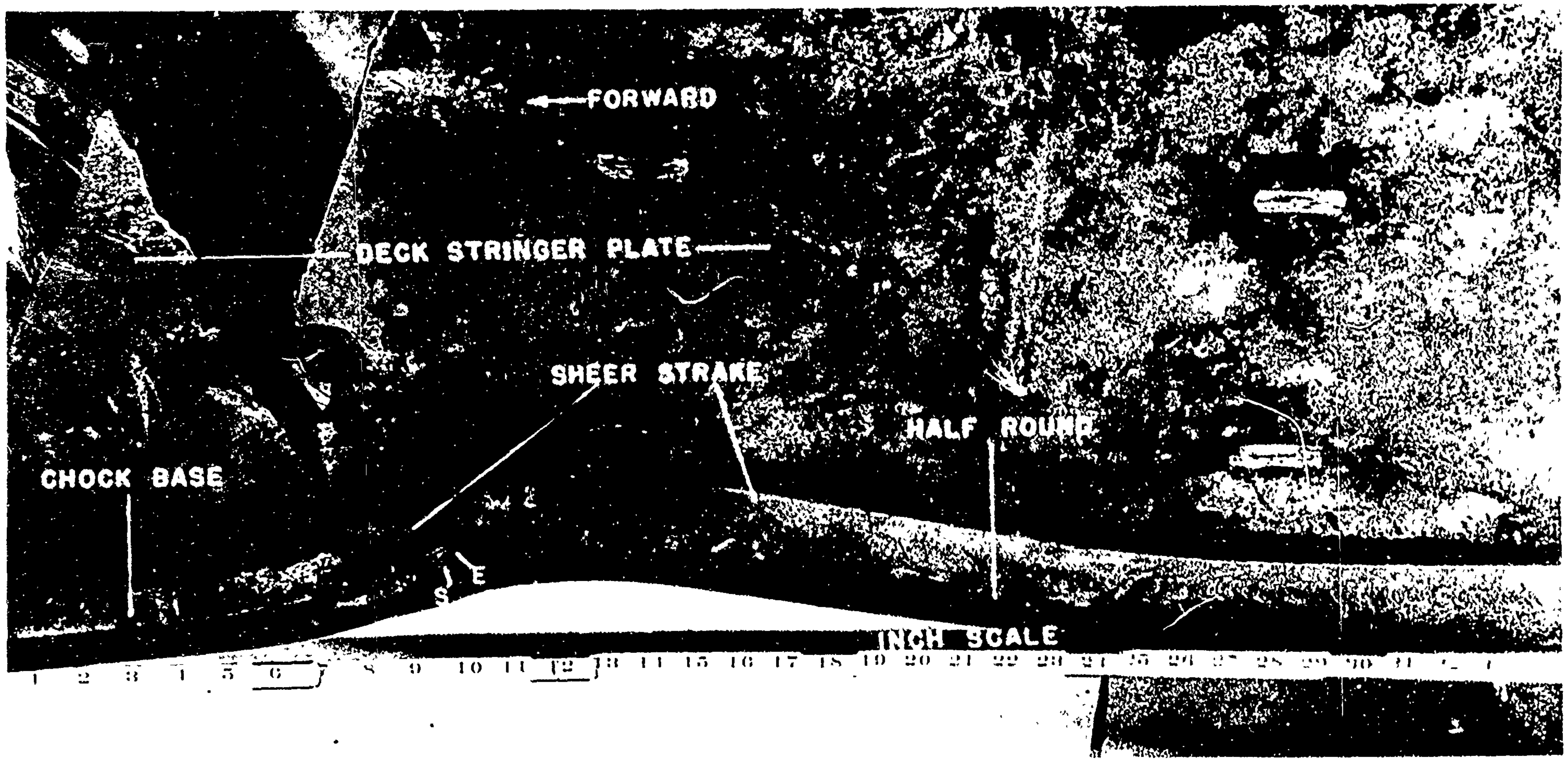

Fig. 7. Fractured parts of half round fitted together, viewed from above. The smooth curvature on both sides of the fracture indicates that the deformation of the half round and the upper sheer strake occurred before the fracture. E shows longitudinal crack at top of half round. S indicates source of main fracture. The missing part of the deck stringer was bent downward - see Fig. 2. x 1/4 approximately.

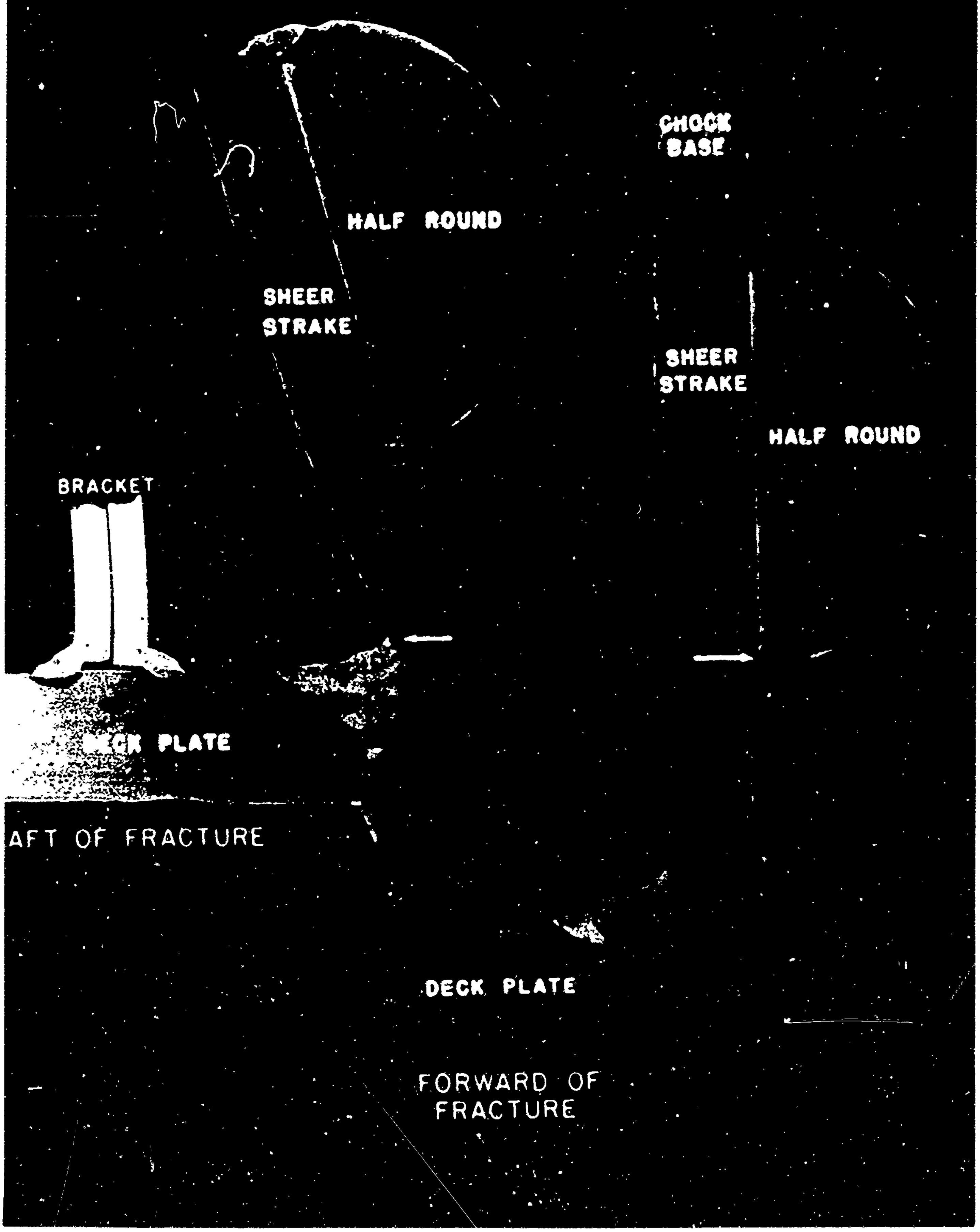

Fig. 8. Cross sections of sheer strake, half round, and deck, port side looking aft. The extent of deformation is shown by the piece at left, taken about 4 inches aft of the fracture. Piece on right, from 9 inches forward of fracture, shows weld connecting chock base to half round and sheer strake. Arrows show small cracks in welds. x 1.

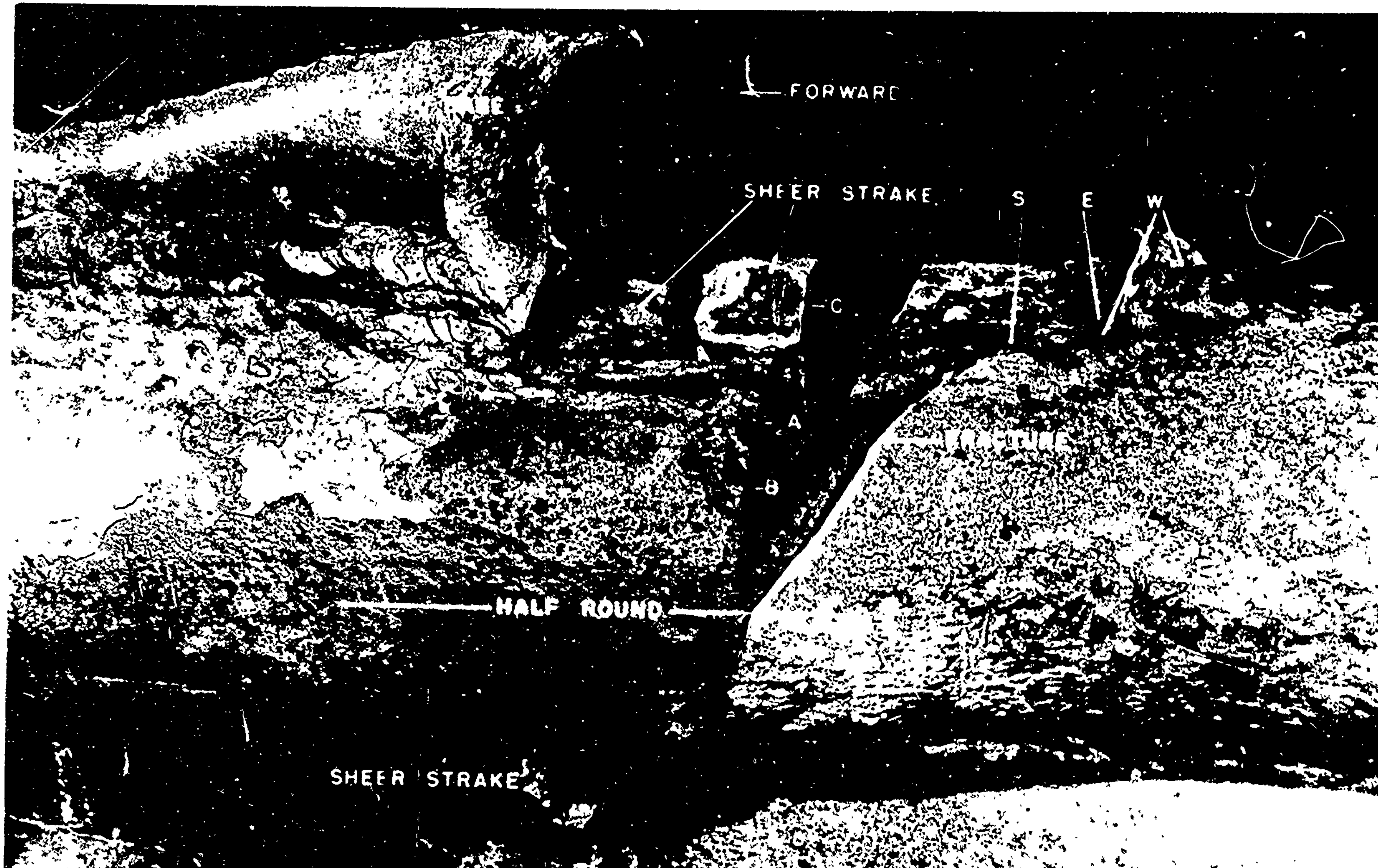

Fig. 9. Fracture in half round viewed from outboard side. Part of the chock base, which originally extended to the weld (w) at the right was lost as a result of battering. B, A, and C indicate the location of specimens cut from the half round and the sheer strake for metallographic examination. x 1.

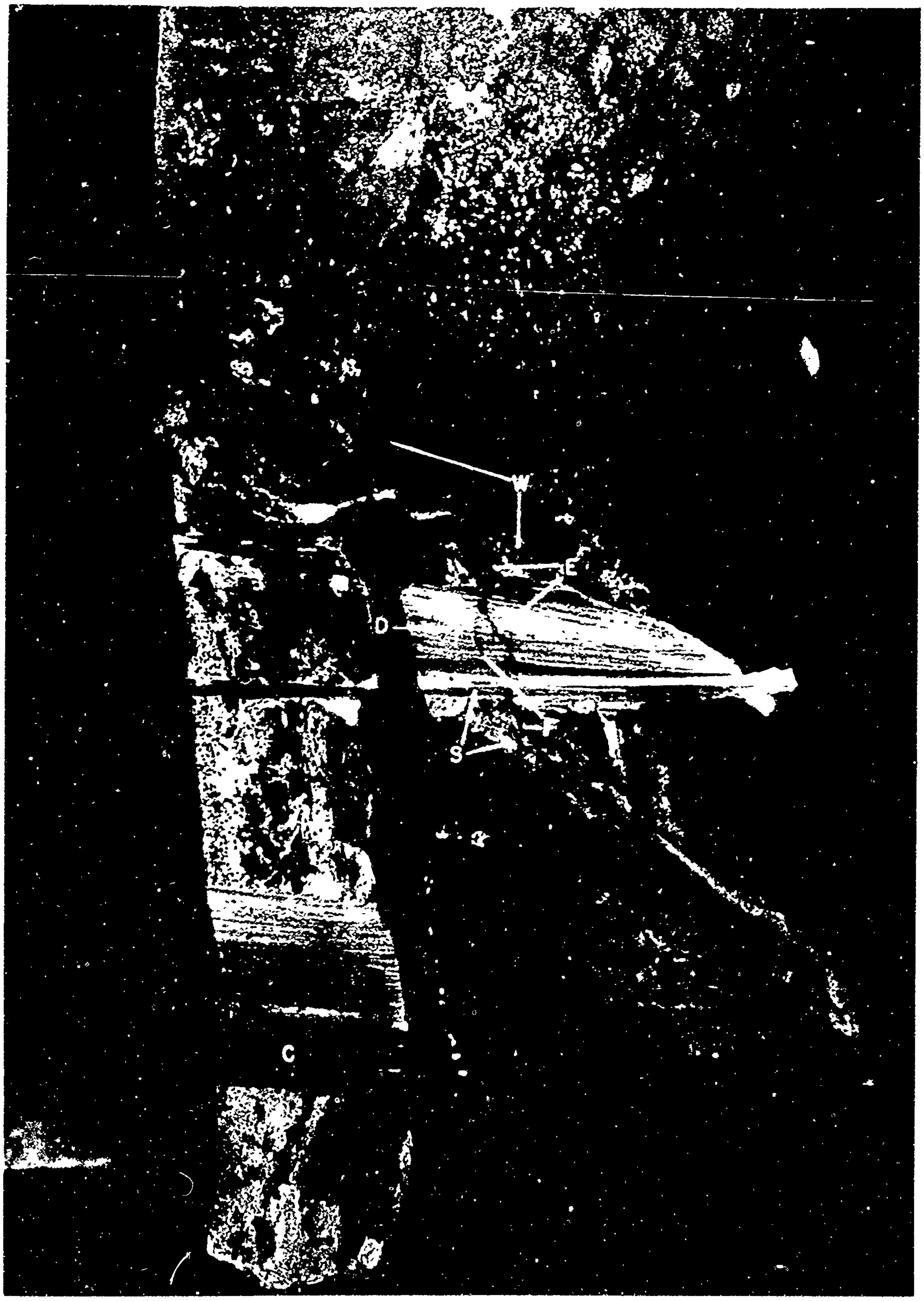

Fig. 10. Top view of half round (right) and sheer strake (left) aft of fracture. C and D show locations of specimens cut from sheer strake and half round for metallographic examination and hardness tests. E and F indicate vertical longitudinal cracks in the top of the half round under the weld (w) to the chock base. S indicates a third vertical crack, which became the source of the main fracture. Note the extent of corrosion in the top parts of cracks E and F. x 2.

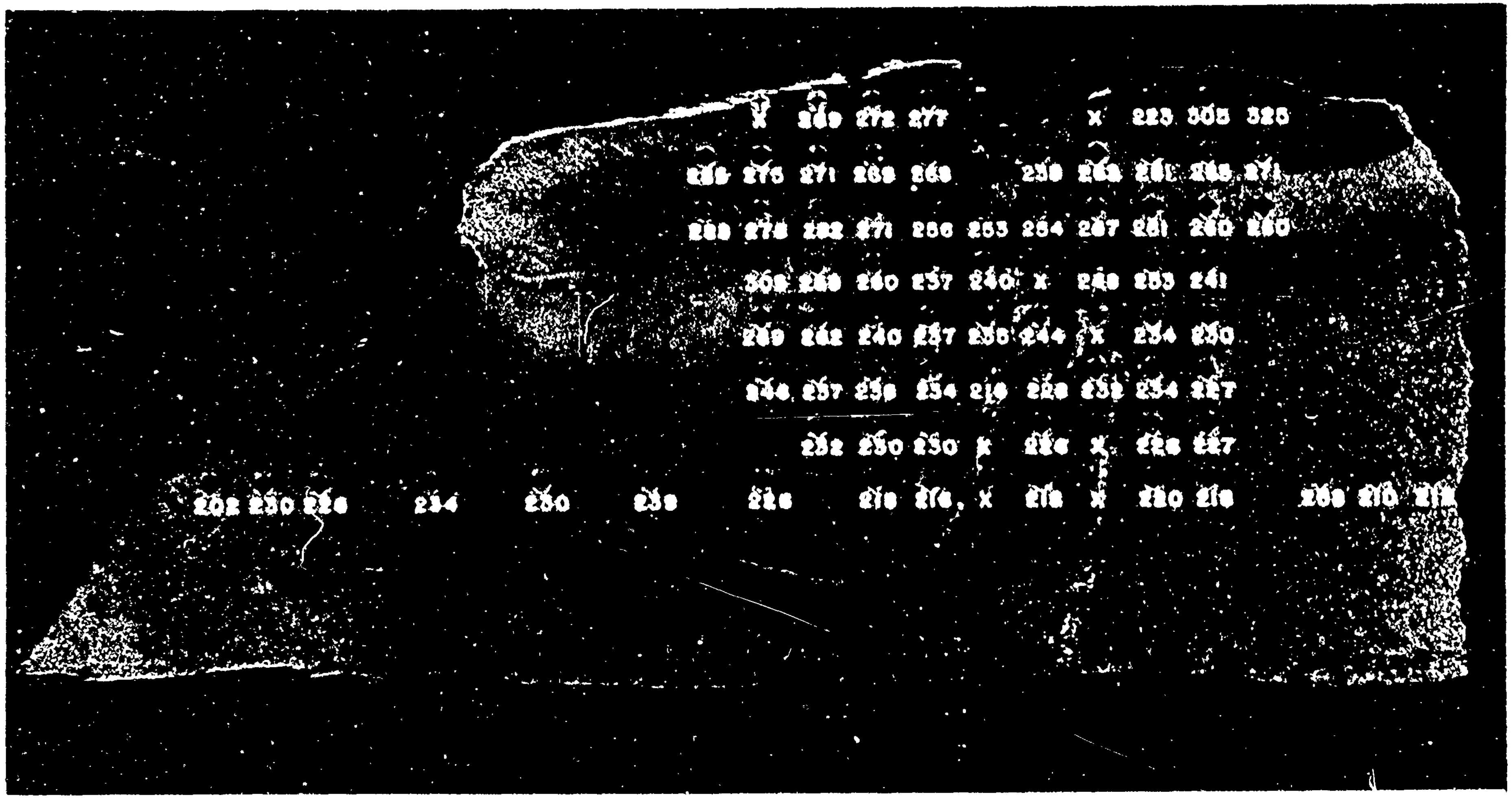

Fig. 11. Hardness impressions and cracks in section from top of half round. (Surface adjoining D in Fig. 10). Vickers Diamond Pyramid Hardness numbers (20 Kg load) are shown under the corresponding impressions. The crack at the top of the specimen (crack E in Fig. 10) started in the overlapping heat affected zones between two weld beads.

x 8.